Coaching patients during pulmonary function testing: A practical guide

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Pulmonary function tests are an important tool to assist in the diagnosis and management of patients with respiratory disease. Ensuring that the tests are of acceptable quality is vital. Acceptable pulmonary function test quality requires, among others, optimal patient performance. Optimal patient performance, in turn, requires adequate coaching from registered respiratory therapists (RRTs) and other pulmonary function laboratory personnel. The present article provides techniques and tips to help RRTs coach patients during testing. The authors briefly review the components of pulmonary function testing, then describe factors that may hinder a patient's performance, list common mistakes that patients make during testing, and provide tips that RRTs can use to help patients optimize their performance.

Key Words: *Diffusion capacity; Flow volume loops; Nitrogen washout; Plethysmography; Quality control; Slow vital capacity*

Les conseils aux patients pendant l'exploration fonctionnelle respiratoire : guide pratique

L'exploration fonctionnelle pulmonaire est un outil important pour contribuer au diagnostic et à la prise en charge des patients atteints d'une maladie respiratoire. Il est essentiel de s'assurer que les tests sont d'une qualité acceptable. Pour parvenir à une analyse des explorations fonctionnelles respiratoires de qualité acceptable, il faut, entre autres, obtenir le rendement optimal du patient. Pour ce faire, l'inhalothérapeute et le reste du personnel du laboratoire de fonction pulmonaire doivent donner des conseils pertinents. Le présent article présente des techniques et des trucs pour aider les inhalothérapeutes à conseiller les patients pendant les tests. Les auteurs analysent brièvement les éléments de l'exploration fonctionnelle pulmonaire, décrivent les facteurs qui nuisent au rendement du patient, énumèrent les erreurs courantes que font les patients pendant les tests et donnent des conseils que les inhalothérapeutes peuvent utiliser pour aider les patients à optimiser leur rendement.

Pulmonary function tests (PFTs) measure lung function. They are important to help diagnose and manage patients with a variety of pulmonary (1-3), cardiac (4,5), neuromuscular (6) or occupational lung diseases (7), assess treatment effectiveness (8,9), follow the pulmonary manifestations of disease (8,10), evaluate disability or impairment (11), and study population lung health (12).

Proper interpretation of PFT results requires acceptable test quality as defined by the 2005 American Thoracic Society (ATS)/European Respiratory Society (ERS) statement series (13-16). Acceptable test quality requires accurate equipment, adequate patient cooperation and optimal patient effort (17). Of these prerequisites, inconsistent patient effort has been observed to result in greater variability in PFT measurements compared with other medical tests (18). In turn, an important cause of inconsistent patient effort is inadequate instruction and coaching by pulmonary function laboratory personnel (19).

In the present article, we first review general principles of instructing patients undergoing PFTs. Then, after a brief overview and description of the individual components that comprise pulmonary function testing, we describe the coaching and instruction that registered respiratory therapists (RRTs) or other pulmonary function laboratory personnel can use to optimize patient effort during each component, list common difficulties patients may experience while trying to attain optimal effort, and suggest tips and techniques to help patients optimally perform the test.

PRINCIPLES OF INSTRUCTION

Instructing patients about proper test performance in a short period of time can be challenging. Although models of instructional design exist (20,21), they rely on lengthy instruction over multiple phases and are difficult to apply to this context. Instead, encouraging optimal effort from patients during pulmonary function testing appears more akin to a trainer boosting athletic performance, in which verbal encouragement has been shown to help (22).

Giving patients a descriptive information pamphlet (23) or showing them a demonstrational video (24) before testing can prime them for what to expect. During testing, the RRT should exhibit enthusiasm, allay the patient's anxiety, convey simple instructions, demonstrate each test, give vocal encouragement and provide feedback on performance. Others have found that observing the patient's nonverbal cues, such as facial expressions and body language, and using one's own body language effectively can enhance the patient's test performance (25). Some of these coaching suggestions are listed in Table 1.

The sequence of events during testing includes instructing the patient on the proper technique, demonstrating the procedure, performing the test on the patient, assessing for acceptability and repeatability, and providing corrective feedback on the patient's technique when needed.

OVERVIEW OF PULMONARY FUNCTION TESTING

While many different tests can evaluate lung function (26), the discussion is limited to the tests included in a typical PFT report. These tests include measurements of the slow vital capacity (SVC), forced vital capacity (FVC) and flow volume loops (FVL), diffusing capacity for carbon monoxide (CO) (DL_{CO}) and lung volumes.

The SVC is a measurement of the tidal volume, inspiratory reserve volume and expiratory reserve volume. These volumes are used together with other tests to measure and calculate all of the volumes and capacities of the lung, including inspiratory capacity and functional residual volume (FRC). The SVC should be performed before FVC because the latter may induce bronchospasm, fatigue the patient

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TABLE 1
General coaching suggestions

Coaching suggestion	Rationale
Provide demonstration and/or video along with description	Enables the patient to see effort expected during the test and clarifies the instructions given
Provide vocal encouragement throughout the test	Encouragement motivates patient to provide maximal effort
Provide feedback on performance	When specific, feedback enables the patient to improve or maintain performance as required

and hamper the test's repeatability (27). The SVC should also be performed before the DLCO measurement. This is because an accurate DLCO measurement requires the patient to inhale at least 85% of the vital capacity (VC); thus, it is important to know the VC beforehand (16).The FVC and FVL are measurements of volume and flow. They are often performed on their own to assess airflow limitations. The DLCO is a measurement of how efficiently the lungs transfer gases across the alveolar-capillary membrane.

Lung volumes are measured using plethysmography. This involves briefly sealing the patient within a body box to derive the FRC, applying Boyle's law relating volume and pressure under constant temperature (28). Lung volumes are also measured using the open-circuit nitrogen (N_2) washout method that washes out N_2 in the lungs using 100% oxygen (O_2) (28).

Each of these components are discussed in more detail.

SVC

The SVC can either be measured during a slow, gentle, maximal expiration after a maximal inspiration or alternatively, during a maximal inspiration following a slow, gentle, maximal expiration (29). At least three acceptable VC trials are needed, and a difference >0.150 L between the first and next largest trial prompts the need for further trials (14). If performed correctly, the patients' SVC should typically be ≥FVC due to the lack of dynamic compression on the airways (29-31).

After demonstrating the test, the patient is instructed as follows:

> Please start with normal breathing. After a few breaths, I want you to fill your lungs completely, then blow out gently all the way until you are empty.

Alternatively, the patient can exhale first and then inhale fully, in which case, he or she is instructed to "fill your lungs as completely as you can" after a complete, gentle exhalation.

Patients may fail to achieve maximal inspiration and expiration, as indicated by the lack of a plateau on the graphical display of the volume versus time curve; this will underestimate their lung volumes. When this occurs, feedback is provided by showing them the graphical display as an incentive to improve their effort on subsequent tests. It has been found that that a tactile cue, such as placing a gentle hand on the shoulder of the patients and telling them to continue their inspiration or expiration until the hand is lifted, can help. Alternatively, a time cue, such as asking them to continue their effort for "another two seconds" (or some other arbitrarily short and achievable duration) is used, once they have almost reached a plateau to coax that last small – but measurable – volume of gas from them. These coaching suggestions are listed in Table 2.

FVC and FVL – pre- and postbronchodilator

FVC is a measurement of the maximum volume of gas a patient can exhale – as forcefully and quickly as possible – after a maximal inspiration. The RRT must obtain three trials of acceptable quality, up to a maximum of eight. Acceptable trials are free from artefact and exhibit satisfactory start and end of test criteria, as defined by the ATS/ERS statement (14).

If the test is being performed to confirm or establish the presence of airflow limitation without treatment, withholding bronchodilators before the baseline test will aid this purpose (32). In this case, the physician may instruct the patient to refrain from using short-acting inhaled medications within 4 h of testing, long acting beta$_2$-agonists within 12 h of testing, and long-acting anticholinergics and leukotriene receptor antagonists within 24 h of testing (32). On the other hand, if the test is being performed to assess a patient's response to treatment, the physician may instruct the patient to continue these medications.

After demonstrating the test, the patient is instructed as follows:

> Please start with normal breathing. Then I want you to take a huge breath in until your lungs are completely full, and blast it out as hard and as fast as you can until you feel you are completely empty and cannot blow out further. Then I want you to take another big, fast, full breath in.

It is critical that the patient takes a maximal inspiration before expiration because a reduced inspiration will lead to a smaller exhaled total volume, likely resulting in data that lack repeatability (33). Patients are reminded to relax their neck and shoulder muscles to avoid syncope.

Patients may perform an exhalation that is hesitating or insufficiently fast at the beginning (leading to a back-extrapolated volume on the FVC, which fails to meet ATS/ERS standards), inadvertently vocalize and partially close their glottis during the test, terminate their effort too soon or incompletely inhale before the exhalation (27).

A hesitating start may be due to transient breath holding between inspiration and expiration: the patient is informed that exhalation should occur immediately after inspiration. If the problem persists because the patient fails to react quickly enough to the instruction to exhale, the command to 'blast' is synchronized so that it occurs just before full inspiration. Of course, the danger then becomes that the patient exhales before maximal inspiration; therefore, this adjustment in timing requires some finesse. Others have observed that startling the patient into a fast exhalation also helps (25).

If patients vocalize during exhalation, this will lead to partial glottic closure, impediment to airflow and data that are not repeatable (27). The difference between exhaling with and without vocalization is demonstrated and patients are reminded to "keep the throat open" to prevent vocalization from occurring.

If patients terminate the exhalation too soon, tactile and time cues as described in the section on the SVC test are used. Also, patients may be instructed to "suck in" their abdominal wall muscles near maximal expiration to distract them from terminating the expiration. Patients often feel as though they have no further volume to exhale long before true maximal expiration; therefore, the RRT needs to provide encouragement and direction until completion of the test. Ultimately, developing a rapport with the patients and securing their trust is instrumental in optimizing their effort and convincing them to continue exhaling when they feel like they cannot. Some of these coaching suggestions are listed in Table 3.

Incomplete inhalation before the exhalation will likely result in data that are not repeatable. As with the SVC test, tactile or time cues are used to coax maximal inspiration from them.

To perform postbronchodilator testing, the RRT should administer four inhalations of 100 µg of salbutamol at approximately 30 s intervals – for a total of 400 µg – using a valved holding chamber. To administer the medication, the patient maximally exhales slowly and the RRT depresses the metered-dose inhaler (after shaking it for 5 s) into the valved holding chamber. Subsequently, the patient maximally inhales the medication from the chamber slowly and holds his or her breath for 10 s. After the RRT has administered all four doses of medication, the patient must then perform three further acceptable trials within 10 min to 15 min after receiving the bronchodilator (14). In clinical practice, the postbronchodilator testing is performed after the other PFT components have been completed.

TABLE 2
Coaching suggestions for slow vital capacity (SVC)

Coaching suggestion	Rationale
Show graphic display of SVC to patient between efforts	This enables the patient to visualize where improvements are required
Use tactile cue (eg, gentle hand to shoulder)	Informing patient to continue inhalation while hand is lifted, and exhalation continues until hand is on shoulder, etc. Can provide encouragement with voice to obtain maximal effort
Use verbal cue (eg, two more seconds, one more second…)	Informing patient how much time is left for exhalation can motivate maximal effort

DLco

During the single breath measurement of DLco, the patient inhales a gas mixture containing 0.3% CO, 21% O_2, 0.3% methane or other tracer gas, and N_2 to make up the balance (34). The patient inhales this gas to total lung capacity after first exhaling to residual volume (16). Inhalation must occur quickly (35), and ≥85% of the total inhaled volume should be inspired in <4 s because lesser volumes cause significant reductions in the DLco (36). The tracer gas is used to estimate this inhaled alveolar volume and also measures the initial dilution of the CO (37). After a 10±2 s breath-holding period starting at total lung capacity, the patient conducts a smooth, gentle exhalation (16) over a period of 4 s and a sample of exhaled breath is collected and analyzed to determine the amount of CO that has transferred across the alveolar-capillary membrane. Two acceptable trials within 3 mL/min/mmHg of one another should be obtained, up to a maximum of five trials, according to the 2005 ATS/ERS standards (16).

If clinically safe, the patient should be off any supplemental O_2 for at least 10 min before the test (16) because an elevated alveolar partial pressure of O_2 can decrease the affinity of hemoglobin for CO (thus, underestimating the DLco). At least 4 min must pass between DLco tests to allow the lung to eliminate the test gas (16).

After demonstrating the test, the patient is instructed as follows:

> Please start with normal breathing. Then I want you to take a big breath in and blow out empty, and as you do this I will switch you to the test gas. After blowing out as much as possible, take the strongest, fullest breath that you can, hold it for ten seconds and then blow it out for me.

Patients may inhale an inadequate volume (<85% of their VC) during the test, leading to a reduced CO uptake and an underestimate of their true DLco (37). Patients also may inadvertently perform a Valsalva manoeuvre (attempted exhalation against a closed glottis) or Muller manoeuvre (attempted inspiration against a closed glottis) during the breath hold. The former could decrease pulmonary capillary blood volume and decrease DLco, whereas the latter could have the opposite effect (38).

To encourage the patient to quickly and smoothly inhale an acceptable volume in the requisite time, “Up, up, up, up!” is exclaimed in an animated voice during inhalation, quickly raising our hand to the ceiling with palm flat and facing upward – similar to a conductor guiding a musician. If patients perform a Valsalva or Muller manoeuvre, they are informed and instructed to refrain from doing it.

Plethysmography

In this test, the patient gently pants – at a frequency of 0.5 Hz to 1 Hz and pressures between ±10 cmH_20 (39) – against a closed shutter at the end of a normal expiration to FRC, creating a pressure change that is measured using a transducer. When there is no airflow, mouth pressure equals alveolar pressure. Compared with the N_2 washout technique (described later), FRC measured using plethysmography (FRCpleth) may be higher in patients with airflow obstruction because it accounts for all thoracic gas, including the gas that is trapped and unable to communicate with the larger airways (15).

TABLE 3
Coaching suggestions for forced vital capacity/flow volume loop

Coaching suggestion	Rationale
Synchronize command to ‘blast’ exhalation to the end of inspiration. Use sharp, forced ‘vocalization’ for command	This can help reduce the tendency to hesitate between inspiration and exhalation and encourages patients to maximize their peak expiratory flow
Use tactile and verbal cues	Similar to slow vital capacity

However, FRCpleth can also overestimate lung volumes in patients who pant at a frequency >1 Hz (39-41) or those with severe airflow obstruction (42). Three to five trials of panting at the appropriate frequency and pressure should be obtained, which will result in a series of straight lines that are almost superimposed on one another on the plot of plethysmograph pressure versus mouth pressure. (43). At least three values of FRCpleth – calculated using the slope of the line in the plethysmograph versus mouth pressure plot – that are within 5% of each other should be obtained and the mean value should be reported (15).

After demonstrating the test, the patient is instructed as follows:

> I will be closing the door on the box for the next test. Please start with normal breathing with your hand pressing gently on your cheeks. I will then close a shutter and cut off your air for a few seconds. While the shutter is closed I want you to gently pant. (Note – we demonstrate the correct panting frequency during our instruction). When the shutter opens up again, you can go back to normal breathing. You do not need to try very hard with this test at all. Tiny, little pants back and forth is all I need.

As the patient is performing the test, the RRT sitting outside the box coaches the patient on his or her technique. It is easiest to perform the tests serially without opening the box door and altering the temperature inside; however, the door may need to be opened for the patient’s comfort.

Patients may pant too fast or too slow, or pant with too little or too much volume. They may pant ‘asymmetrically,’ with one part of the pant (either inhalation or exhalation) performed correctly but the other part of the pant performed incorrectly. Alternatively, patients may be too anxious or claustrophobic to sit in the box.

To coach panting at the appropriate frequency, some use a metronome (15). We move our hands back and forth to demonstrate the correct panting frequency and use the force of our hand motions to signal the use of more or less panting volume. For patients who are unable to sit in the box despite our reassurances and coaxing, we perform an N_2 washout ($FRCN_2$) to obtain FRC.

$FRCN_2$

The $FRCN_2$ uses an open-circuit system in which the patient breathes 100% O_2 for several minutes until the amount of exhaled N_2 is washed out of the lungs (28). At least one test must be obtained. If the patient is on supplemental O_2, they need to be off this for at least 15 min before the test (15).

After demonstrating the test, the patient is instructed as follows:

> Please just breathe normally throughout this test. You are breathing through a regulator so it will feel a bit like you are breathing through a straw. When I switch you over to the oxygen supply, you may hear a ‘click’ as the valve opens. The test will take a few minutes, so please do not take the mouthpiece out of your mouth. Your mouth may get dry and it may be difficult to swallow while using the mouthpiece. Please make sure that your lips are sealed tightly and your nose clip is on properly. If you need to take a bigger breath, that is OK. I will let you know when the test is over.

Patients may fail to seal their mouth completely around the mouthpiece, and any increase in N_2 >1% indicates a leak – that is, the patient has inadvertently inhaled atmospheric N_2 and subsequently exhaled it into the collected gas. In this case, the test should discontinued and repeated after approximately 15 min (15). This test only measures gas that can communicate with the large airways; therefore, it is typically used if the patient cannot be sealed within the box for FRCpleth.

CONCLUSION

The present article provided tips on how to coach patients to achieve acceptable and repeatable trials during pulmonary function testing. One of the most challenging things about coaching patients is knowing how to adapt instructions because some patients will need more assistance than others. It is helpful if one can explain the same test in different ways. Exaggerated body language helps, especially when a language barrier is present.

Although it has been shown that RRTs and other pulmonary function laboratory personnel who participate in workshops can improve their attainment of the ATS/ERS standards for spirometry (44), further research is needed to determine the specific coaching strategies and adjuncts that help optimize patients' performance.

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